Advanced Fracturing Technologies for Marginal Oil and Gas Wells

Scott R. Reeves, (sreeves@adv-res.com, Phone: 713-780-0815)
Advanced Resources International
9801 Westheimer, Suite 805
Houston, TX 77042

DOE Contract: DE-AC21-94MC31112
Period of Performance: Oct. 1994 – Sept. 1999
FETC COR: Jim Ammer

Introduction

In 1994, the DOE/FETC began a field-based R&D project to investigate the application of "new and novel" fracture stimulation technologies for gas storage wells. The project was initiated in response to the persistent decline in deliverability that occurs in gas storage fields, reported to be on the order of 5% per year. To counteract that decline, industry currently spends about $100 million annually; two-thirds of which is used to drill infill replacement wells. However, in the highly competitive post-FERC 636 market environment, a more cost-effective approach to maintaining deliverability is required. A study published by the GRI in 1993 suggested that fracturing holds considerable promise in this regard, and DOE/FETC responded with this project.

Similar to the needs and economic pressures of gas storage wells, marginal oil and gas wells may also benefit from the fracturing technologies investigated in this project. Such wells, typically characterized by low reservoir energy and/or tight formations, can be highly susceptible to damage by stimulation fluids, similar to gas storage wells. In addition, due to marginal economics particular attention must be paid to the stimulation costs, and the production (or deliverability) results obtained therefrom. This paper discusses the technologies and results of the DOE/FETC gas storage project, and how they might be applicable to marginal oil and gas wells.

Objectives

The fundamental objective of the project is to demonstrate the application and economic feasibility of "new and novel" fracturing technologies for restoring the deliverability of existing underground gas storage wells. Within this primary objective, several tactical objectives are as follows:

- Identify "new and novel" fracture stimulation methods that hold potential for gas storage wells.
- Demonstrate their application, including treatment design, implementation and results.

- Evaluate their economic performance as compared to "typical" (non-fracturing) stimulation practices of gas storage operators, such as blowing/washing or mechanical cleaning of the wellbore, reperforating, water/solvent washes, and acidizing.

Approach

The approach utilized for the project was to test the "new and novel" fracture stimulation technologies in various geologic and reservoir settings across the U.S. Four different technologies were tested at nine field sites. At each site, three "new and novel" treatments were performed, and compared to the results of one "control" well where the operator's typical stimulation technique was applied. To understand treatment mechanics, state-of-the-art design procedures were utilized together with on-site diagnostics and post-treatment analysis. Treatment effectiveness was determined using multi-point deliverability and pressure transient testing with downhole instrumentation; tests were run before a treatment, afterwards and again one year later to determine long-term impact. Cost/benefit analyses were performed to estimate the economic benefit of the "new and novel" methods as compared to non-fracturing stimulation techniques.

Technology Description

Gas storage wells have a number of unique characteristics that require special attention when considering fracture stimulation. First, due the high-permeability nature of most gas storage formations, the desired fracture geometry is short in length with high conductivity. This is to bypass near-well damage and create a highly conductive flowpath to the wellbore. Second, fracture height growth is of concern due to the potential for gas loss. Therefore, treatments that minimize the potential for upward or downward growth are required. Finally, due the cycling of dry, pipeline quality gas into and out of gas storage wells, water saturations can be at sub-residual levels. Therefore, the introduction of aqueous fluids tends to be "damaging" to gas permeability. Treatments must therefore minimize this effect. With these criteria, four technologies were selected for testing.

- Tip-screenout fracturing. This hydraulic fracturing technique is ideal for creating short, highly conductive fractures in high permeability formations. However, relatively large volumes of aqueous-based fluids are required and the potential for height growth exists.
- Hydraulic fracturing with liquid CO_2 and proppant. This technique utilizes a non-aqueous carrier fluid to completely avoid the fluid-damage issue, hence providing immediate stimulation benefits. However, high proppant volumes and concentrations cannot be pumped, limiting fracture conductivity.
- Extreme overbalance fracturing. This method involves exposing the target formation to a high-pressure pulse of nitrogen, thus creating fractures. The technique utilizes small fluid volumes and the potential for height growth is minimized.
- High energy gas (propellant) fracturing. This method utilizes propellants which are ignited and burned to form a small volume of high-energy gas that fractures the formation. Multiple, radiating fractures are created and, similar to the above method, the potential for height growth is minimized.

Results

Significant findings that are relevant to the application of these technologies to oil and gas wells are:

- Tip-screenout treatments are extremely effective at enhancing deliverability in high-permeability, high-pressure wells.
- Liquid CO_2 with proppant treatments provide immediate stimulation benefits and avoid a prolonged fluid cleanup time. However, fluid leakoff appears to be a problem, and hence their application is probably limited to where pump rate can overcome fluid loss. While treatment costs are higher than aqueous-based treatments of comparable volume, this is offset by the greater immediate well response. These treatments also appear to be effective in cleaning up hydrocarbon residue damage due to the solvent characteristics of CO_2.
- Extreme overbalance treatments suffer from operational complexity, high cost and poor understanding.
- High energy gas fracturing is operationally simple and low in cost, but the fractures created, being unpropped, provide stimulation of uncertain durability.

Application

Of the techniques investigated, several are likely to be of benefit to marginal oil and gas wells. Tip-screenout treatments are best suited for higher permeability formations with sufficient remaining pressure for effective cleanup; hence, their application to marginal oil and gas wells may be limited. Liquid CO_2 with proppant treatments seem well suited to water-sensitive tight gas wells, provided sufficient fracture length can be achieved. Lack of fluid damage, which maximizes flush production, should be sufficient to offset the higher cost. In addition, the solvent characteristics of CO_2 make it attractive for oil wells. Extreme overbalance treatments are probably not well suited for marginal oil and gas well applications, but for cost reasons, high-energy gas fracturing may be for the same reason (cost).

Acknowledgement

This work was performed under DOE/FETC contract number DE-AC21-94MC31112, "Field Verification of New and Novel Fracture Stimulation for the Revitalization of Existing Underground Gas Storage Wells", with a period of performance from October 1, 1994 through September 30, 1999. The Contracting Office Representative is James R. Ammer, (jammer@fetc.doe.gov, Phone 304-285-4383). Industry partners were Columbia Gas Transmission, Consumers Energy, CNG Transmission, East Ohio Gas, KN Energy, MichCon Gas, National Fuel Gas Supply, and Natural Gas Pipeline. Significant subcontractors included NSI Technologies and John F. Schatz Research and Consulting

ADVANCED FRACTURING TECHNOLOGIES FOR MARGINAL OIL AND GAS WELLS

by

Scott Reeves

Advanced Resources International, Inc.

DOE Contract: DE-AC21-94MC31112

FETC COR: James R. Ammer

DOE Oil & Gas Conference

June 28 - 30, 1999

Dallas, Texas

PRESENTATION OUTLINE

- Introduction
- Objectives
- Approach
- Technology Description
- Results
- Application

BACKGROUND

- **Project initiated in 1994:**
  - **"Application of New and Novel Fracture Stimulation Techniques to Enhance the Deliverability of Gas Storage Wells."**
- **DOE responds to an industry need:**
  - **Persistent deliverability decline (>5%/year).**
  - **High cost of deliverability maintenance ($100 million/year, two-thirds for infill replacement wells).**
  - **Fracturing identified as a potentially more efficient path to maintaining deliverability.**

CONCERNS AND SPECIAL ISSUES WITH FRACTURING IN GAS STORAGE WELLS

- **Fracture Height Growth**
  - Gas Loss
  - Water Production
- **High Permeability Formations**
  - High Fracture Conductivity
  - Short Fractures to Bypass Damage
- **Fluid Sensitivity**
  - Gas Permeability Reduction, Long Cleanup Times
  - Particulate Damage
  - Chemical Reactions
- **Tight Economics**
  - No tangible gas "reserve" to offset costs
  - How to value improved deliverability?

COMPARISON OF GAS STORAGE AND MARGINAL OIL/GAS RESERVOIRS

	Gas Storage	Marginal Oil/Gas
Depth	Similar	Similar
Permeability	higher	lower
Pressure	can be higher	probably lower
Fluid Sensitivity	high	high
Economics	marginal	marginal

PRESENTATION OUTLINE

- Introduction
- Objectives
- Approach
- Technology Description
- Results
- Application

PROJECT OBJECTIVE

- To demonstrate, through a series of field tests, the application and benefits of "new and novel" fracturing technologies that directly address these challenges and obstacles and that can enhance the long-term deliverability of gas storage wells.
  - Identify potential fracturing methods.
  - Demonstrate their practical application (design, implementation).
  - Compare them, commercially, with traditional methods.

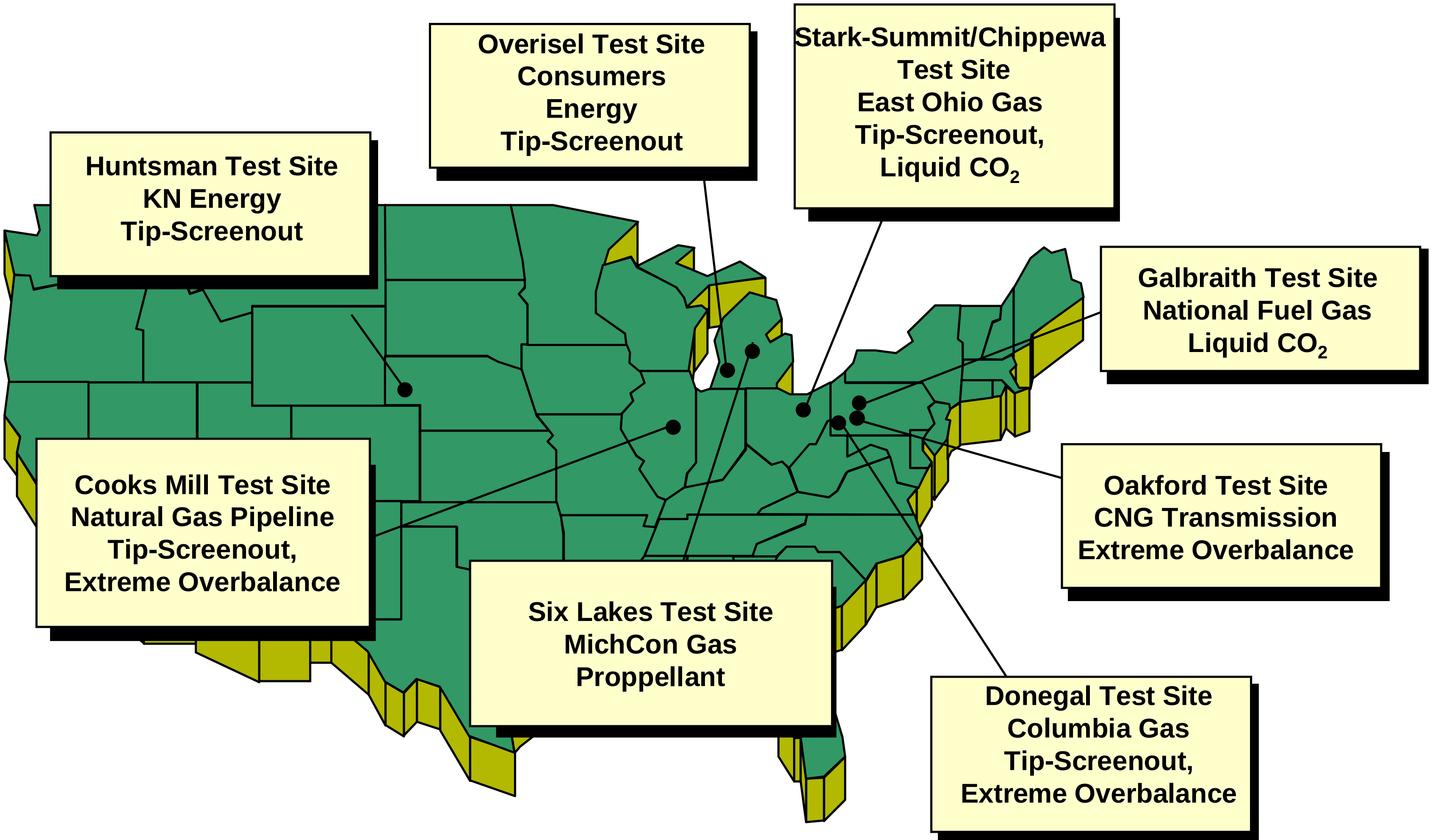
PRESENTATION OUTLINE

- Introduction
- Objectives
- Approach
- Technology Description
- Results
- Application

PROJECT OVERVIEW

- Nine field projects
- Each project consists of multiple wells:
  - Target of 3 “new and novel” fracture test wells
  - At least one “conventional” stimulation control well
- Detailed design and diagnostics:
  - pre-, post- and annual multipoint deliverability and pressure transient tests with downhole instrumentation
  - rock mechanics studies, fracture height surveys
  - treatment design and post-analysis modelling
- Economic and benchmarking analysis

LOCATION OF TEST SITES



SUMMARY OF FIELD ACTIVITIES PERFORMED TO DATE*

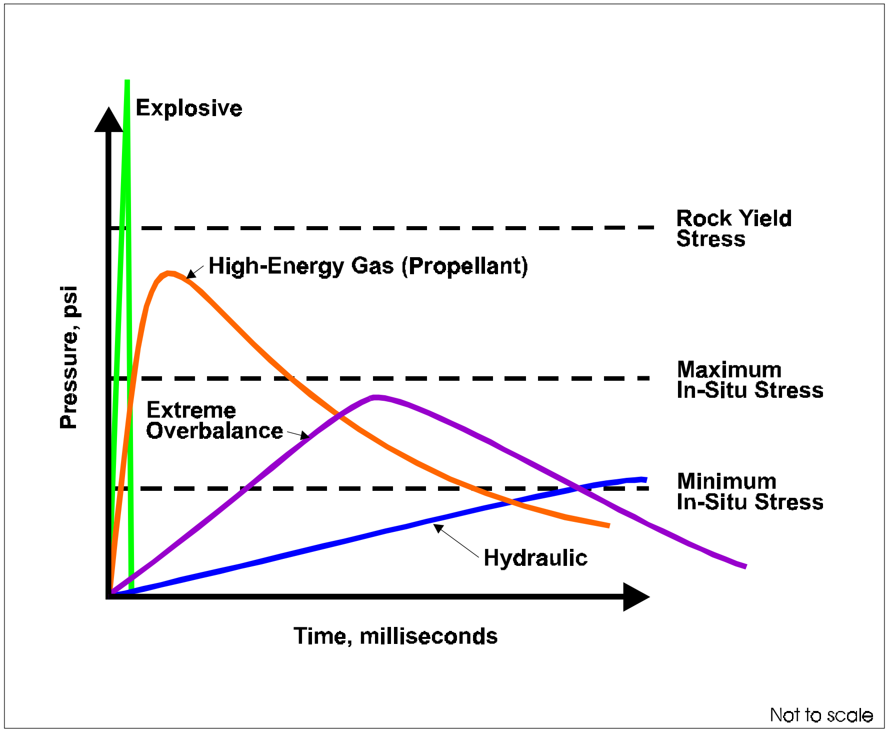
	Tip-Screenout				Liquid CO_2		Extreme Overbalance		Propellant	
Activity	**Huntsman**	**Stark-Summit/ Chippewa**	**Overisel**	**Cooks Mills**	**Galbraith**	**Stark-Summit/ Chippewa**	**Donegal**	**Oakford**	**Six Lakes**	**Total**
New and Novel Fracture Treatments Performed	2	3	3	1	3	3	7	2	3	27
Pre-Fracture Deliverability and Pressure Transient Tests Performed/Analyzed	7	18	4	4	4	13	16	4	4	74
Acoustic Logs Run/Analyzed	-	-	-	-	-	-	1	-	-	1
Core Plugs Taken/Tested	-	-	-	-	-	-	6	-	-	6
Step-Rate Tests Performed/Analyzed	2	1	3	-	-	-	2	-	-	8
Mini-Fracs Performed/Analyzed	4	1	3	-	-	-	1	-	-	9
Main Frac Bottomhole Treating Pressure Records	2	-	3	-	-	1	-	2	3	11
Radioactive Tracer Surveys	3	1	1	-	-	-	5	-	-	10
Temperature Surveys	3	2	-	-	-	-	-	-	-	5
Downhole Camera Surveys	-	-	-	-	-	-	-	1	7	8
Post-Fracture Deliverability and Pressure Transient Tests Performed/Analyzed	3	4	2	3	3	2	13	2	3	35
Annual Deliverability and Pressure Transient Tests Performed/Analyzed	2	3	2	-	3	1	13	3	-	27

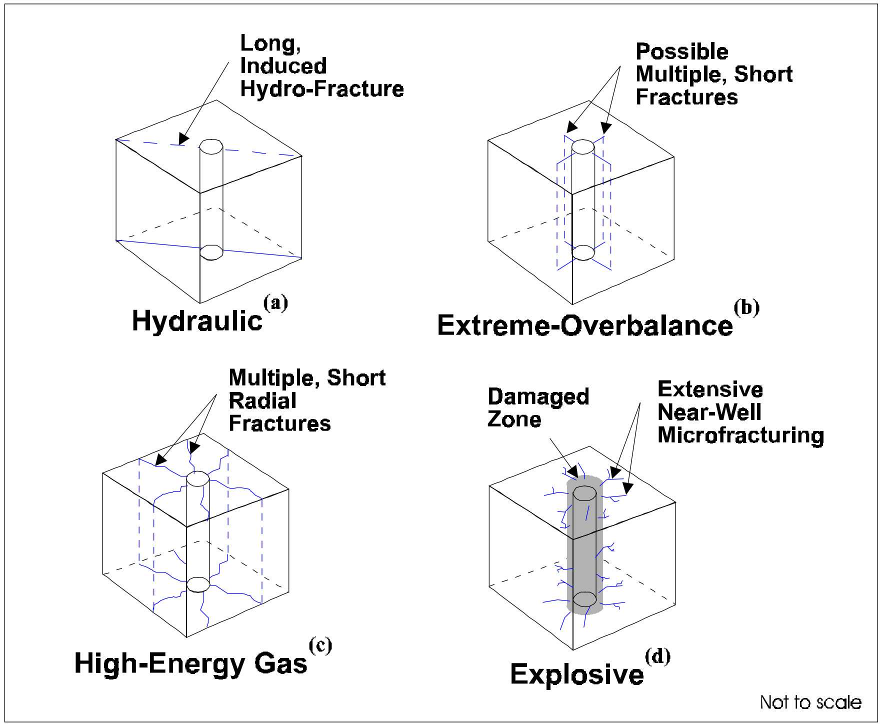
* As of June 1999

PRESENTATION OUTLINE

- Introduction
- Objectives
- Approach
- Technology Description
- Results
- Application

ENERGY APPLICATION RATES AND RESULTING FRACTURE PATTERNS FOR VARIOUS FRACTURE-STIMULATION TECHNOLOGIES





“NEW AND NOVEL” FRACTURE STIMULATION TECHNOLOGIES

Hydraulic
<u>Fracturing</u>

- **Tip-Screenout**
- **Liquid CO_2 w/Proppant**

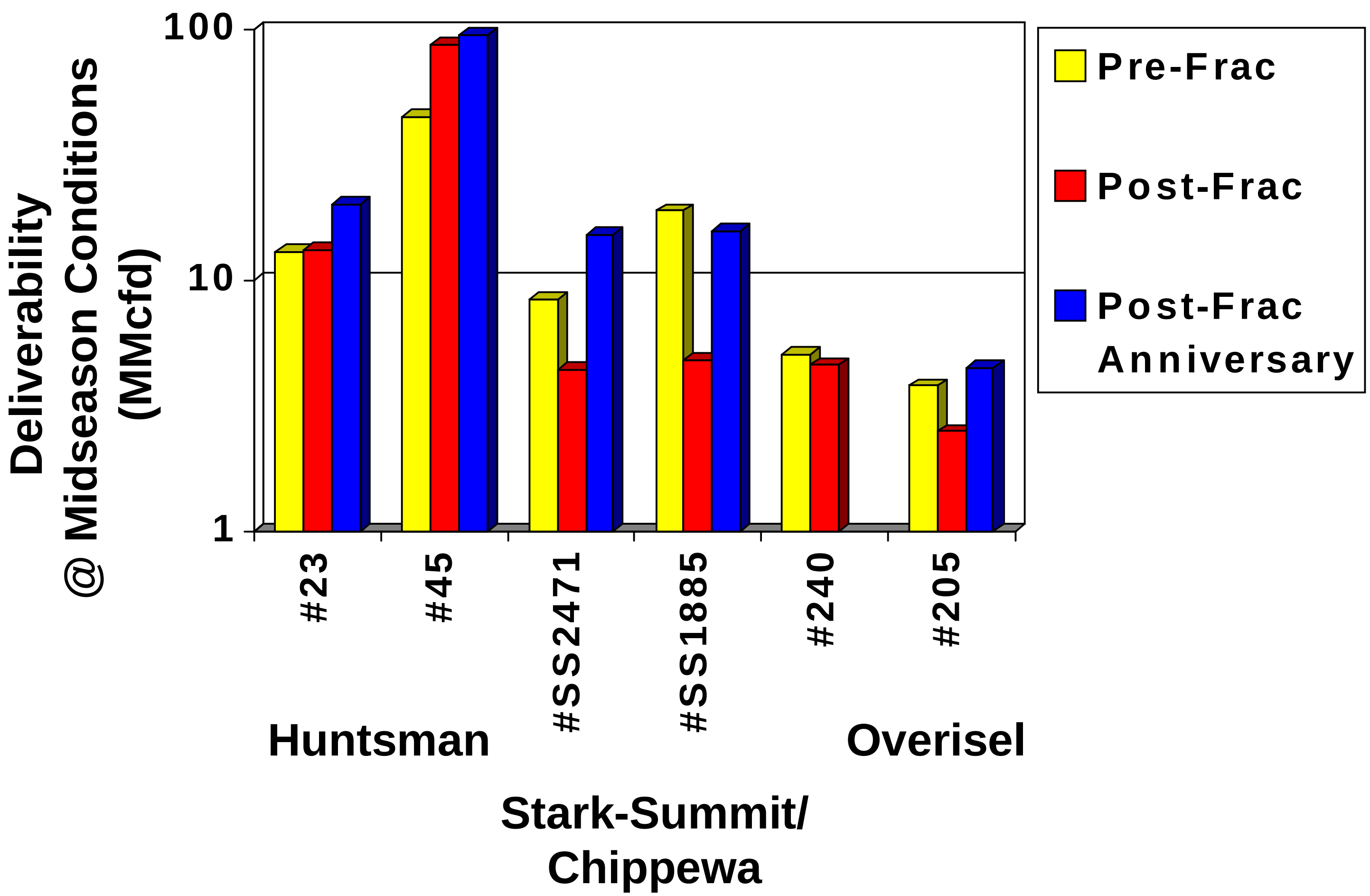
Pulse
<u>Fracturing</u>

- **Extreme Overbalance**
- **Propellant**

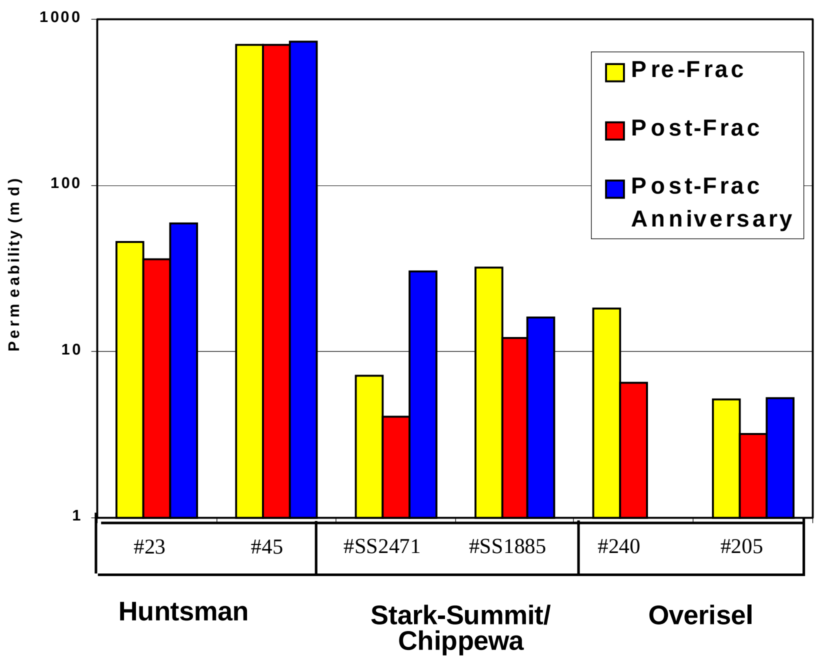
PRESENTATION OUTLINE

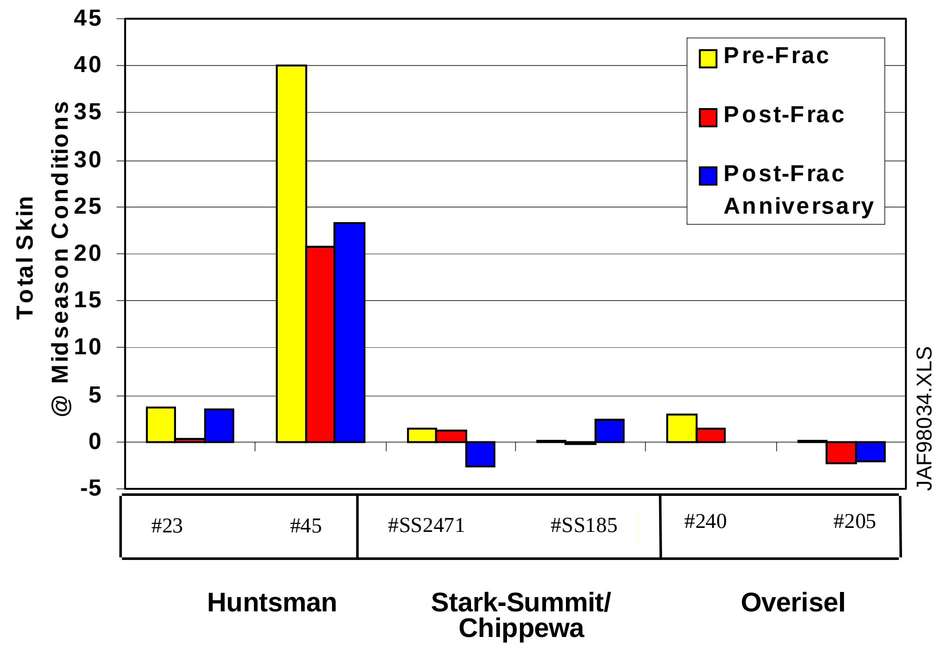
- Introduction
- Objectives
- Approach
- Technology Description
- Results
- Application

DELIVERABILITY RESULTS, TIP-SCREENOUT TREATMENTS

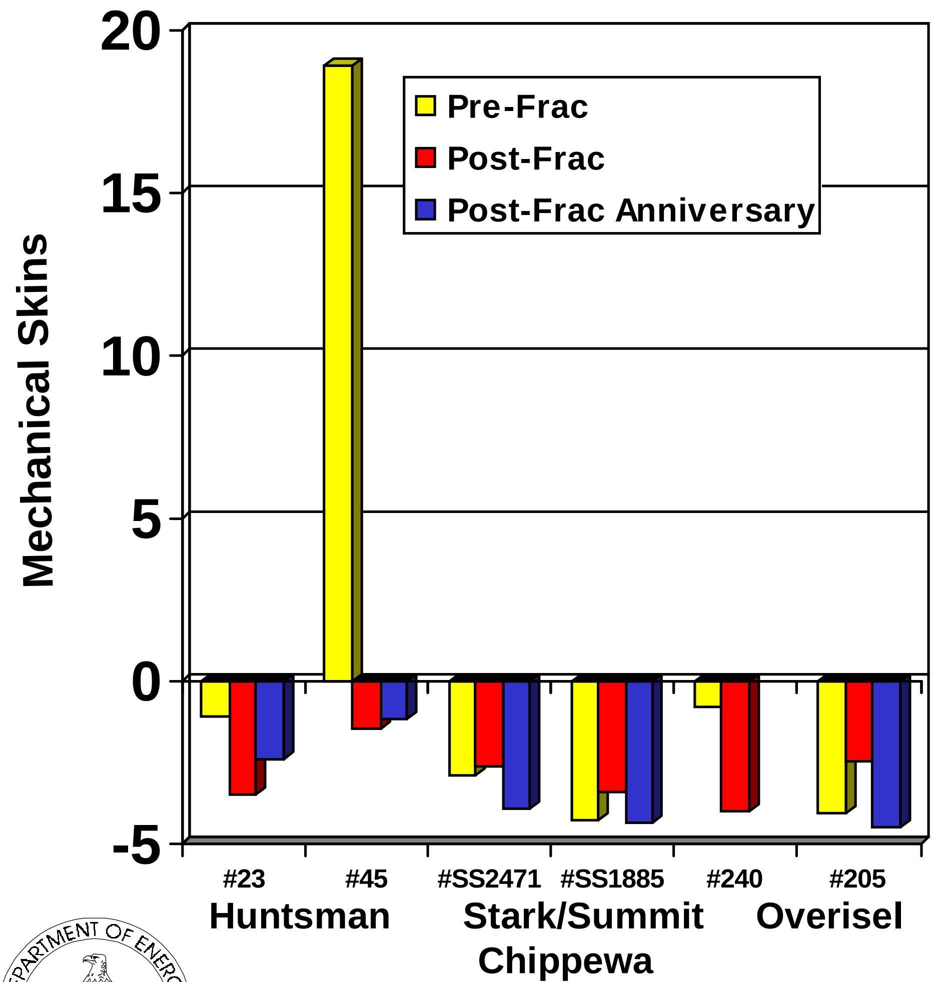


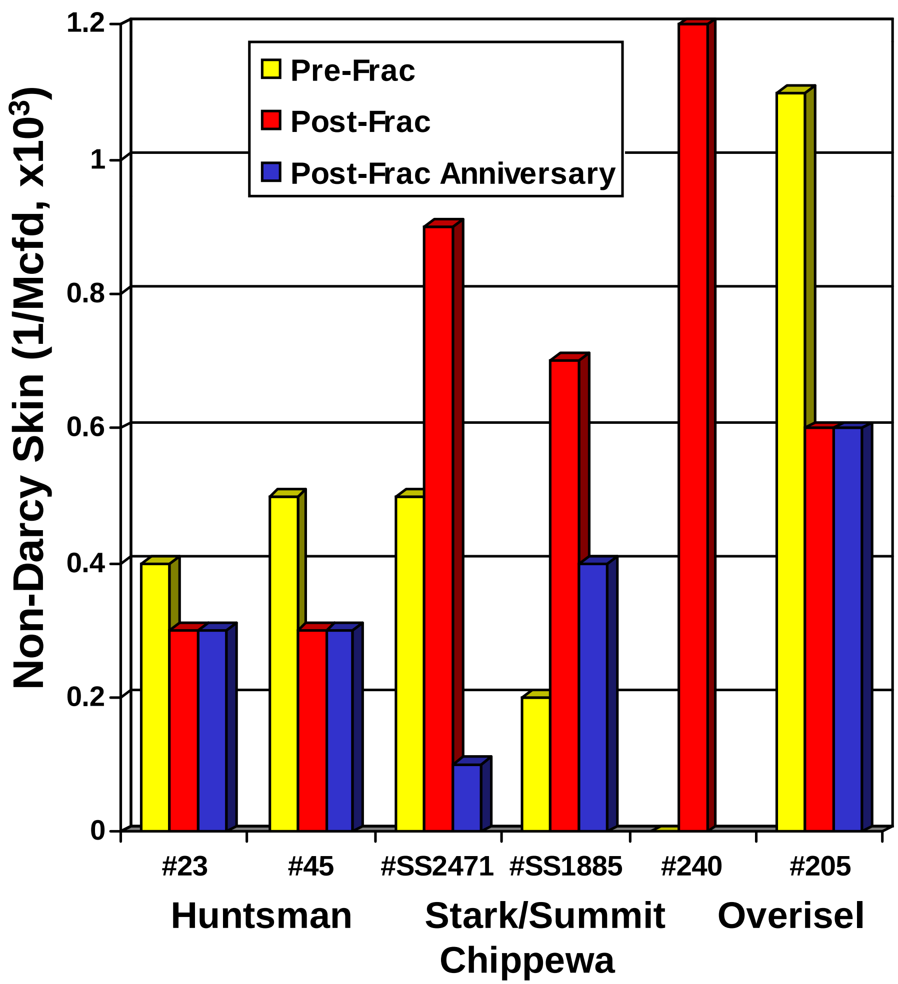
TRANSIENT ANALYSIS RESULTS, TIP-SCREENOUT TREATMENTS



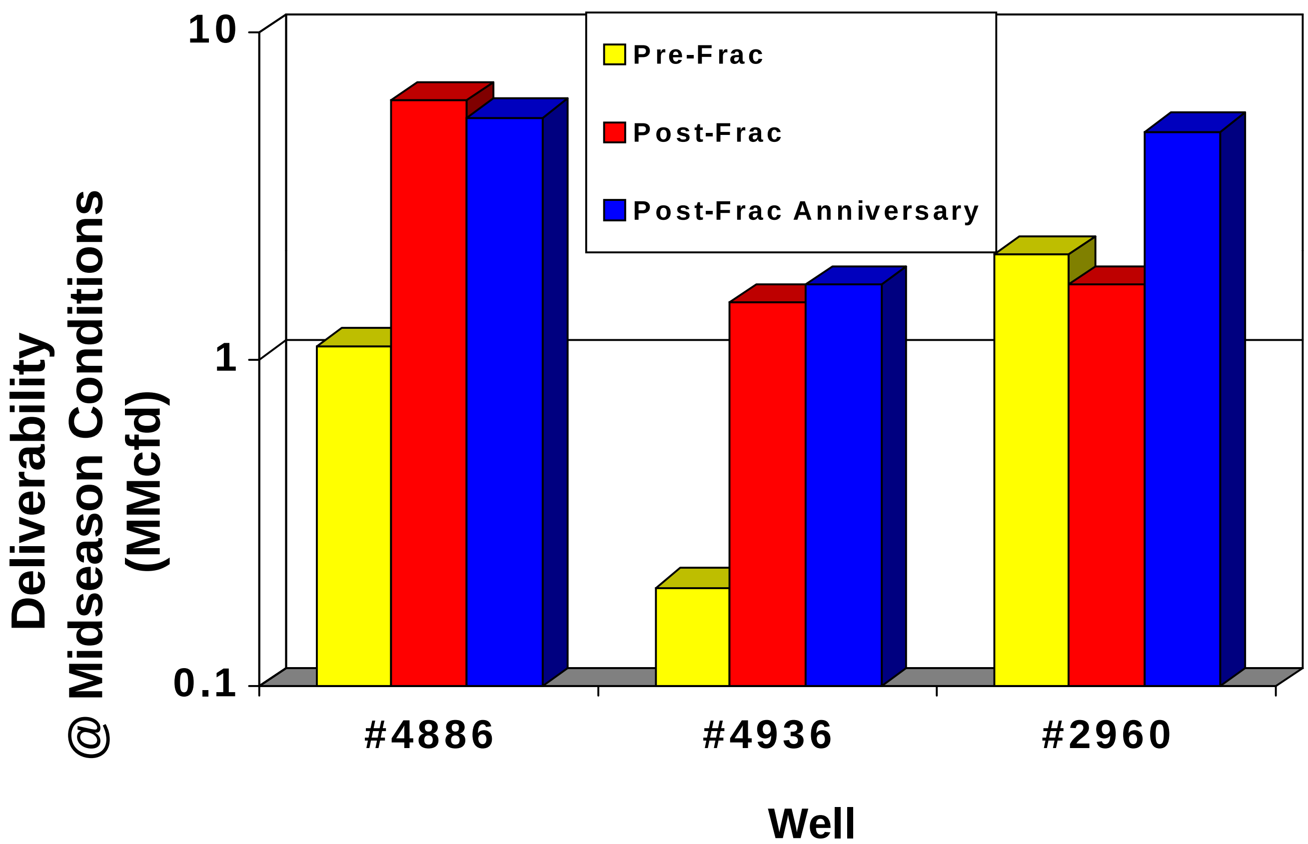


SKIN EFFECT COMPONENTS, TIP-SCREENOUT TREATMENTS

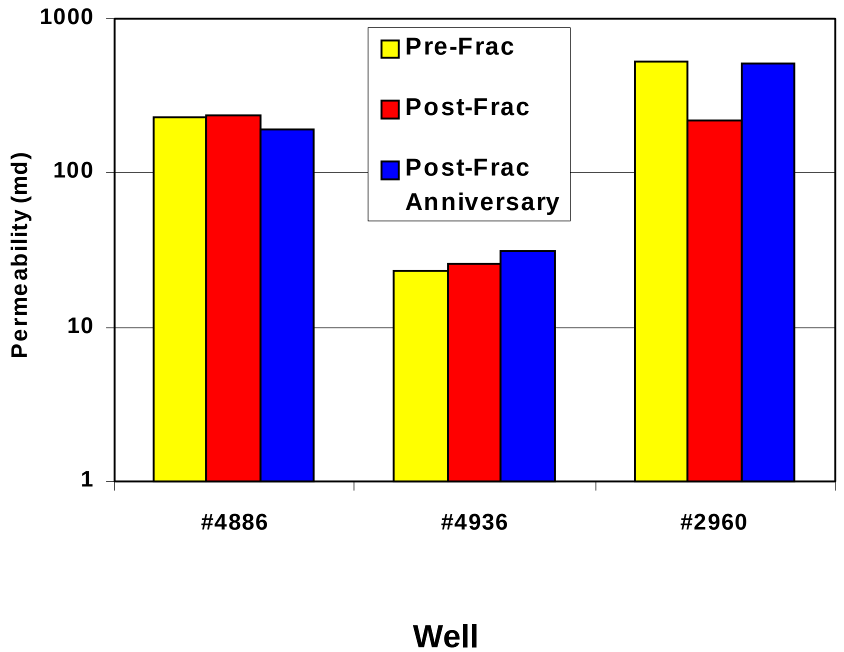


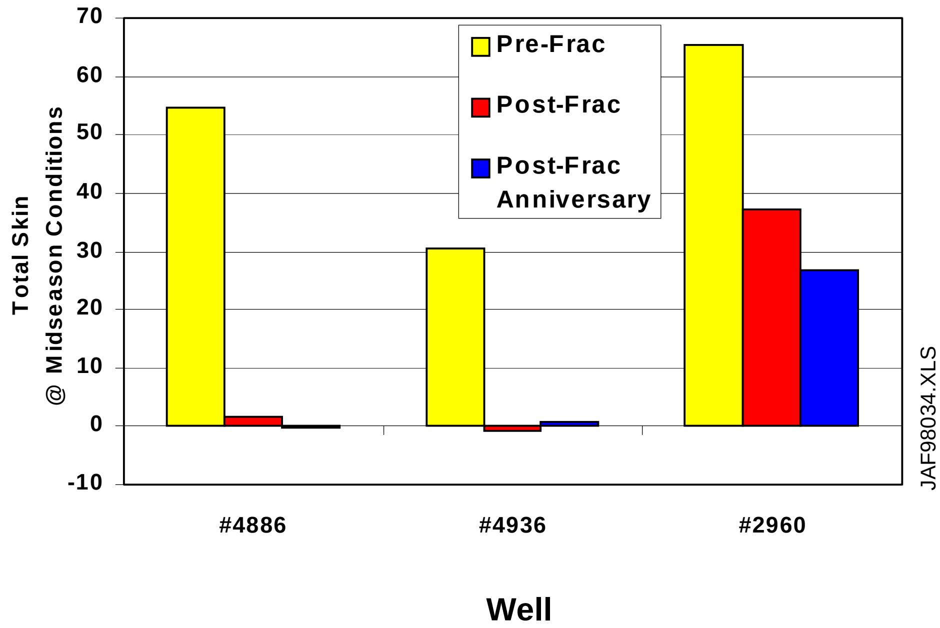


DELIVERABILITY RESULTS, LIQUID CO_2 W/ PROPPANT TREATMENTS

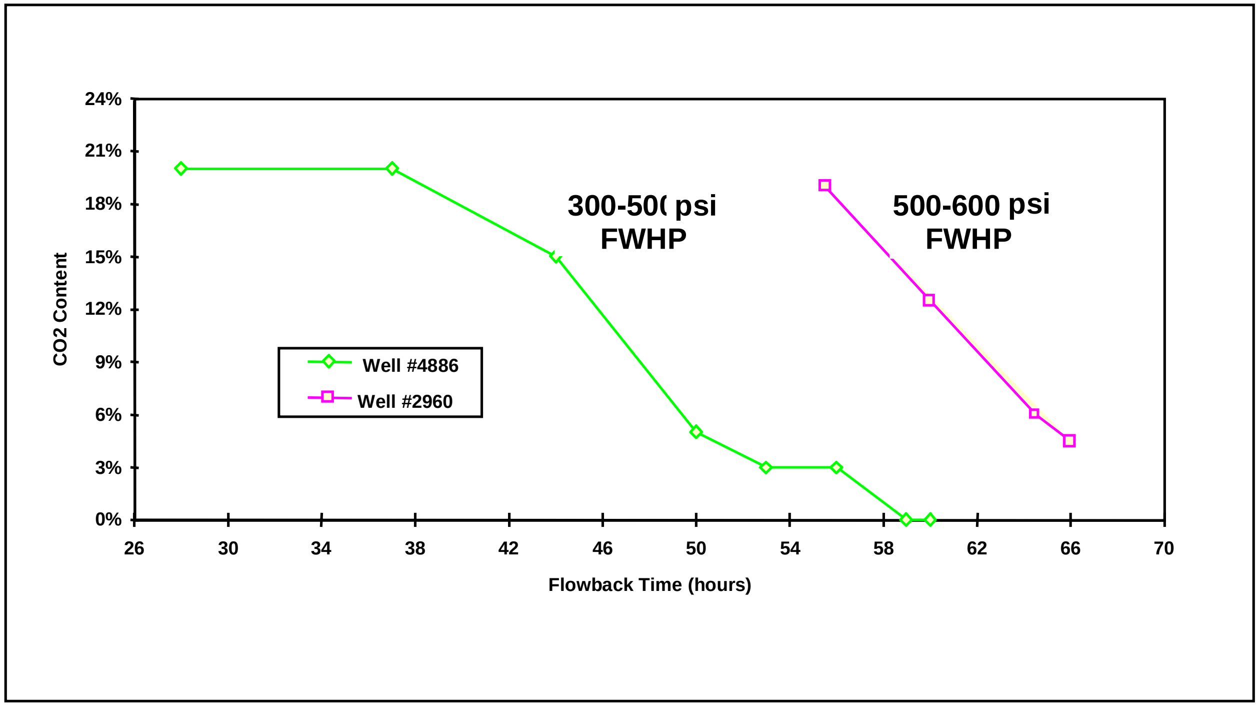


TRANSIENT ANALYSIS RESULTS, LIQUID CO_2 W/PROPPANT TREATMENTS

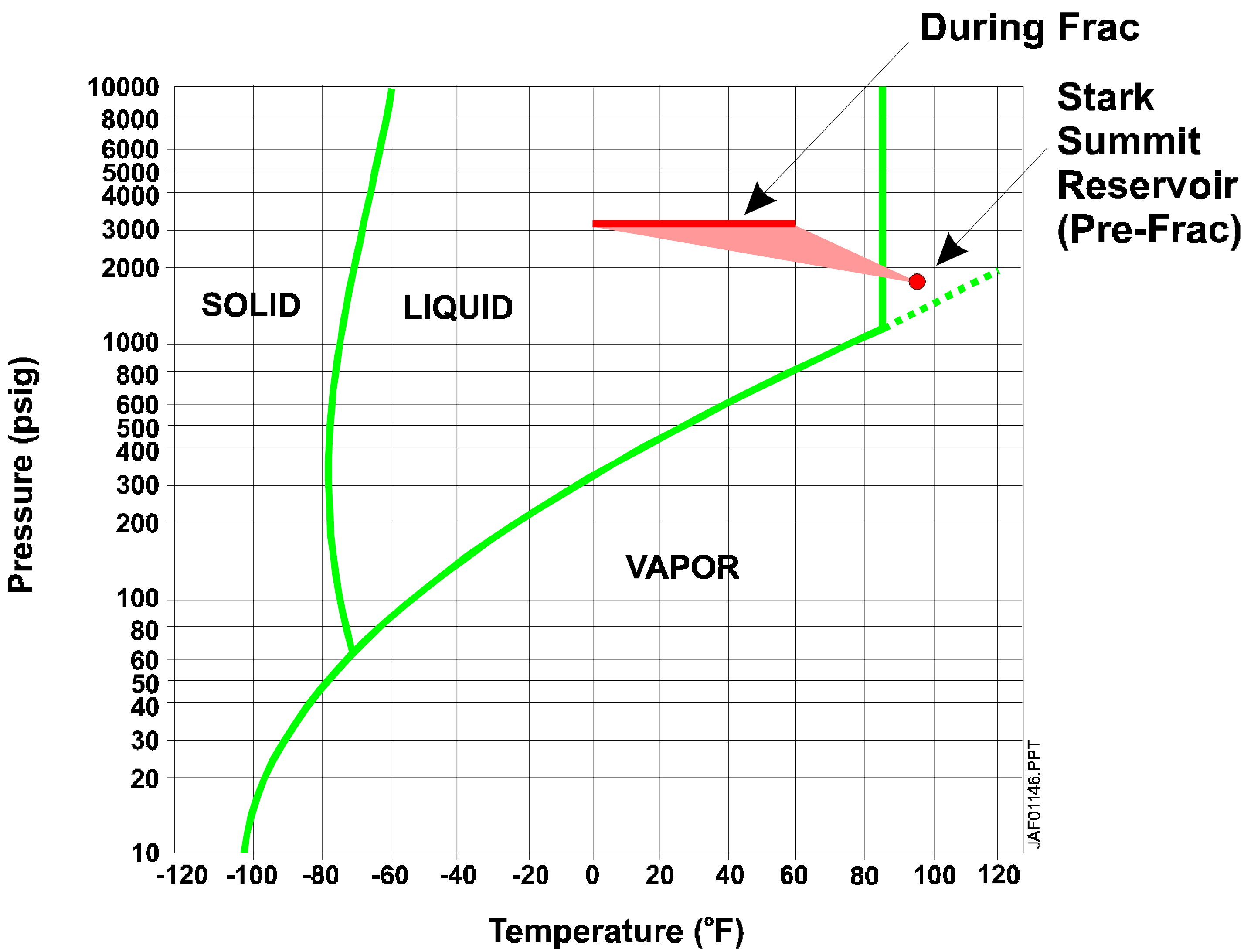




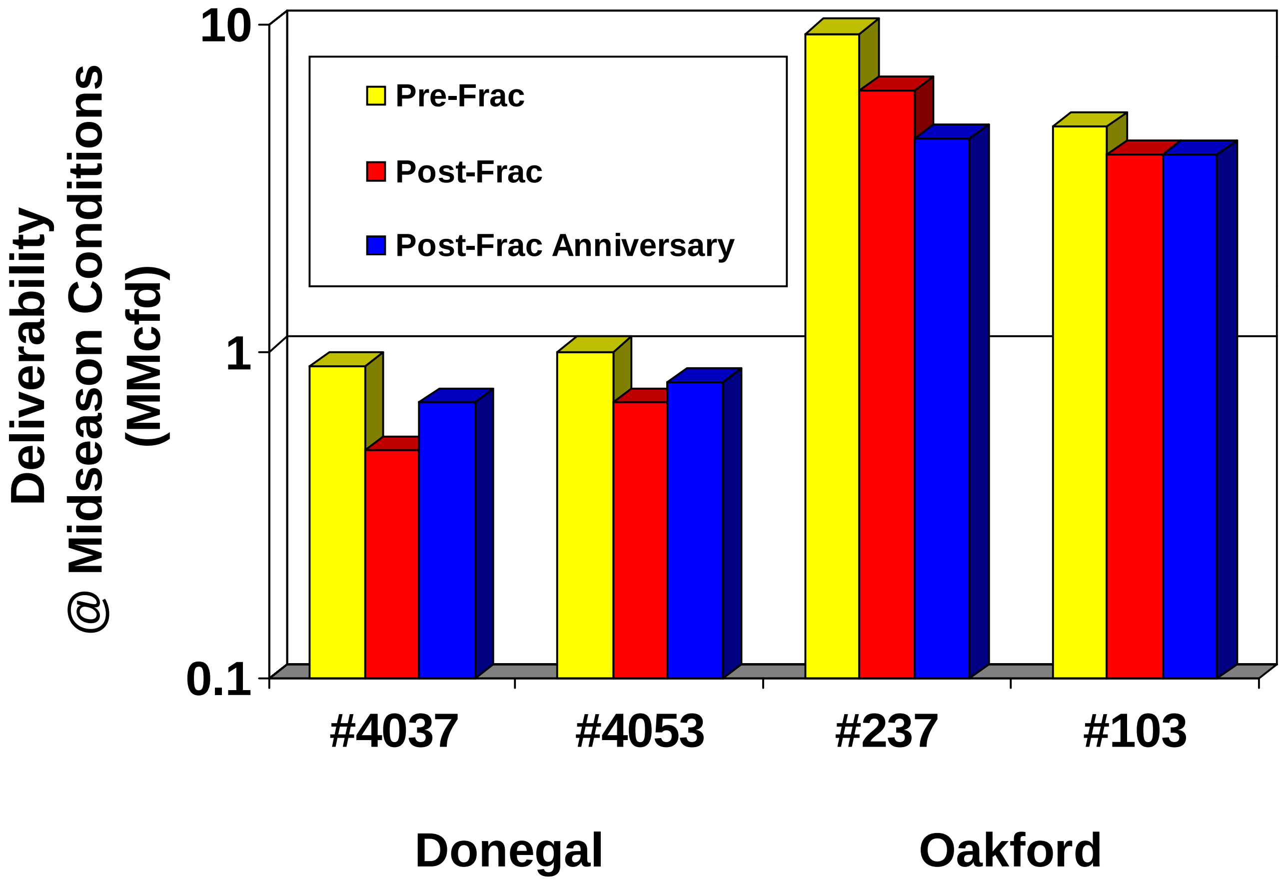
CO_2 CONTENT OF FLOWBACK GAS, GALBRAITH TEST SITE



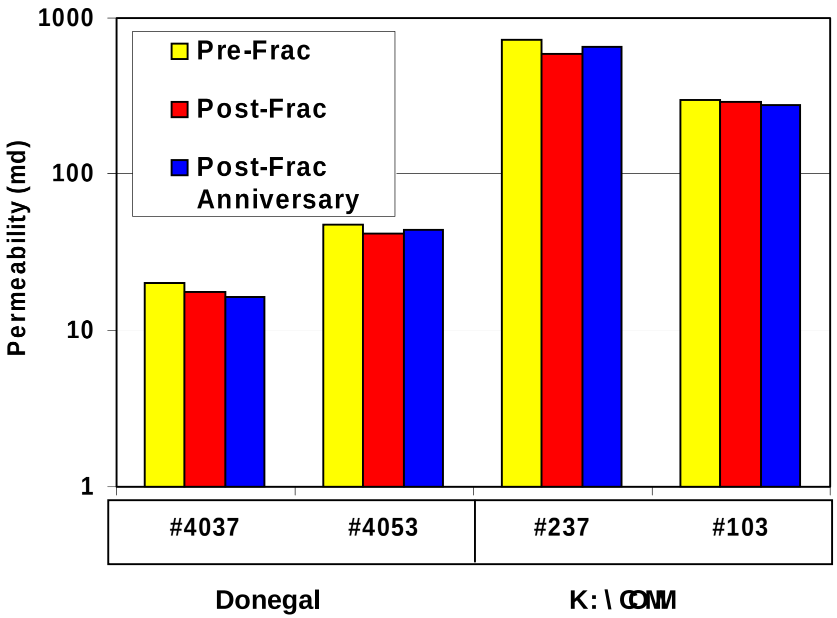
CO_2 PHASE DIAGRAM

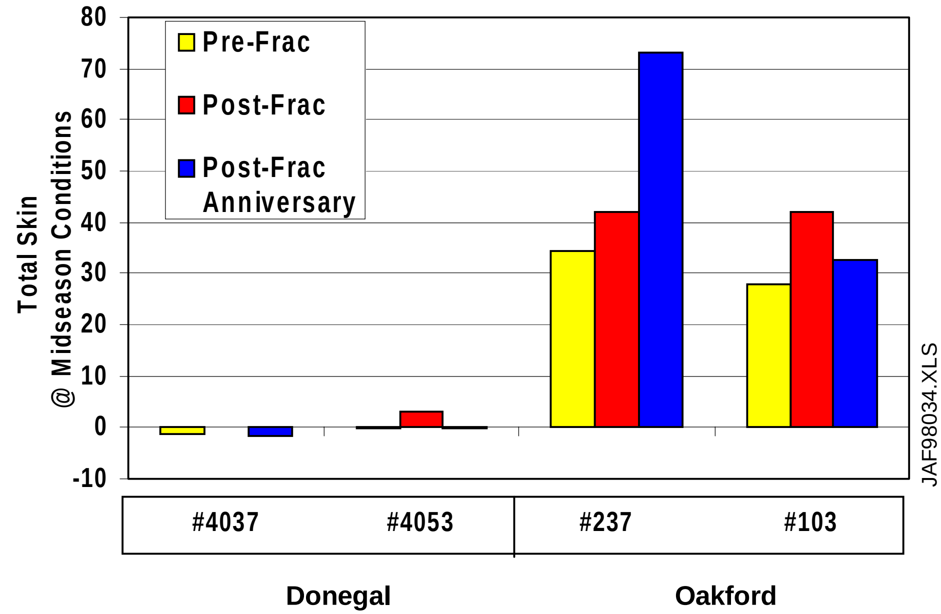


DELIVERABILITY RESULTS, EXTREME OVERBALANCE TREATMENTS

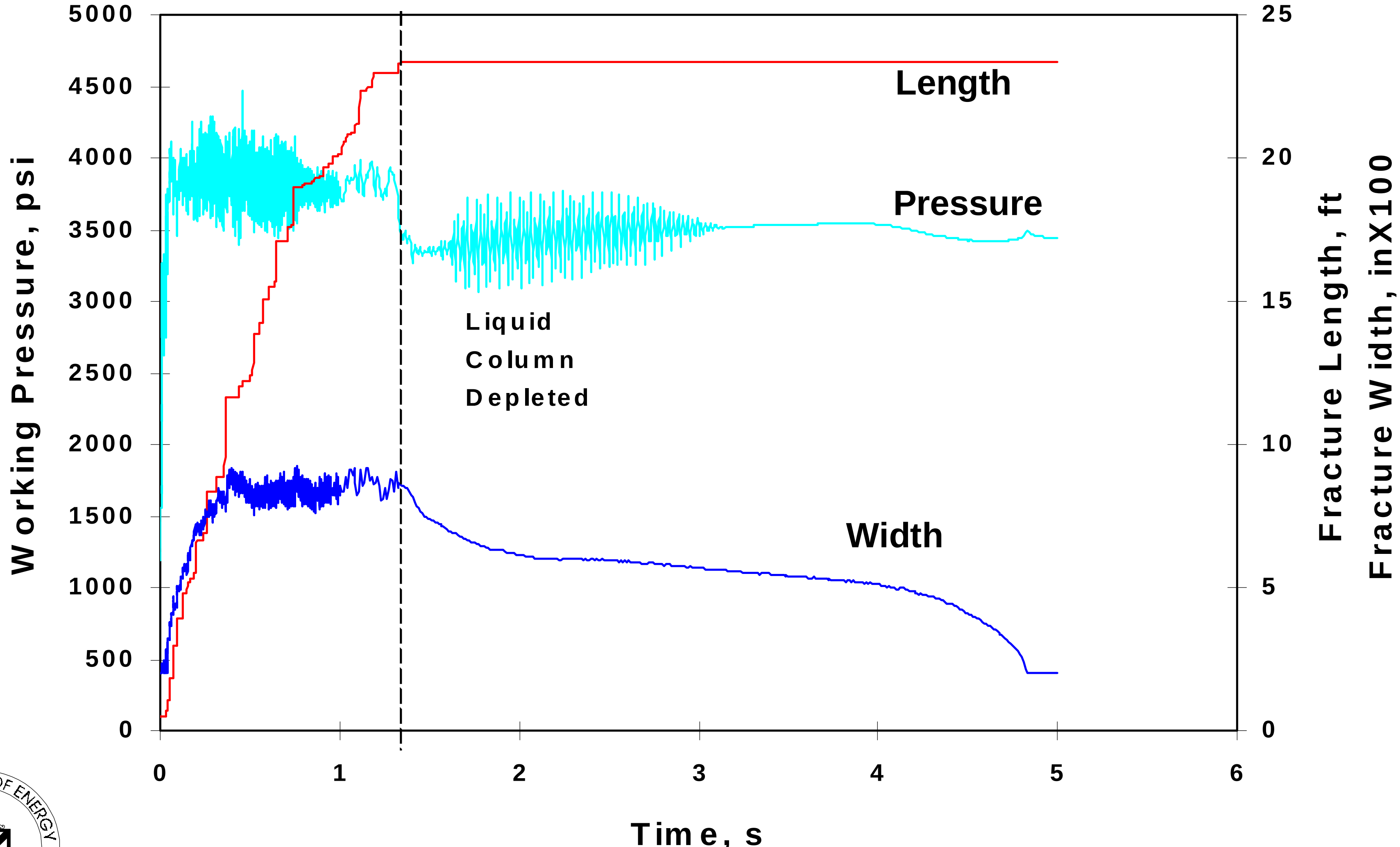


TRANSIENT ANALYSIS RESULTS, EXTREME OVERBALANCE TREATMENTS



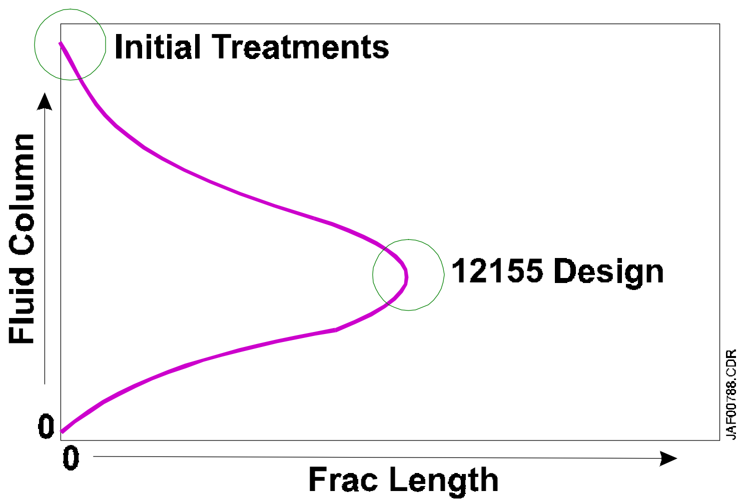


EXTREME OVERBALANCE DESIGN, DONEGAL 12155



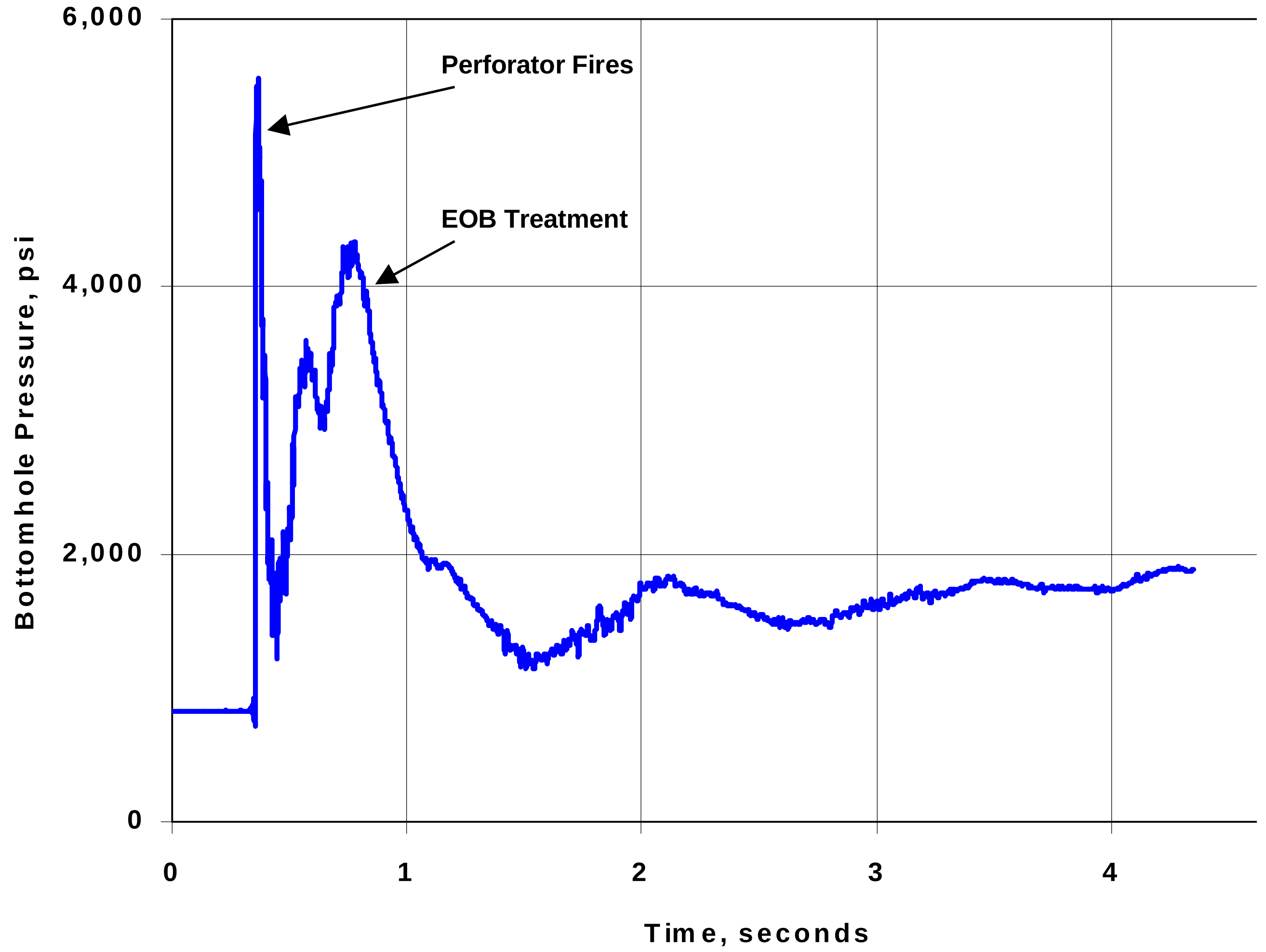
IMPORTANT EOB DESIGN VARIABLES

- **Relationship between maximum pressure, fluid volume, fluid column height:**



- **Continued nitrogen pumping after initial surge provides no benefit.**

DOWNHOLE PRESSURE RECORD OF EOB TREATMENT, OAKFORD #103



COST BENEFIT ANALYSIS RESULTS FROM EACH TEST SITE

Test Site	New and Novel Technology	Benchmark Method	Cost of Deliverability Maintenance ($/Mcfd/Yr)	
			New & Novel	Benchmark
Huntsman	TSO	Coiled tubing cleanout	$0.08	$0.77
Stark-Summit/ Chippewa	TSO	Conventional hydraulic fracturing	$0.05	$0.08
Overisel	TSO	Acidizing	$0.21	$0.47
Donegal	TSO	Reperforating	$0.79	$37.71
Galbraith	Liquid CO_2	Conventional hydraulic fracturing	$0.98 (actual) $0.36 (successful efforts)	$0.50
Donegal	EOB	Reperforating	$4.28	$37.71
Oakford	EOB	Coiled tubing cleanout	Not operationally successful	$0.12

SUMMARY OF FINDINGS

- **TSO Treatments**
  - **Highly effective at improving deliverability in high-permeability, high-rate wells; reduction in non-Darcy flow is an important contributor to this.**
  - **Fluid cleanup appears more problematic in low-volume wells.**
- **Liquid CO_2 Treatments**
  - **As anticipated, immediate deliverability improvements with no cleanup effects observed.**
  - **Some difficulty in pumping proppant (leakoff, fracture width, proppant transport) suggests specific window of application.**
  - **Higher cost can be offset by better short-term results.**

SUMMARY OF FINDINGS (cont'd)

- **EOB Treatment**
  - Lack of engineering design tools can inhibit treatment success.
  - Can be operationally complex and costly.
  - Convergence with propellant technology may prove key to success.

PRESENTATION OUTLINE

- Introduction
- Objectives
- Approach
- Technology Description
- Results
- Application

POTENTIAL APPLICATION TO MARGINAL OIL/GAS WELLS

- TSO treatments may not be well suited for this application:
  - best suited for high-rate wells
  - damage potential
  - fluid cleanup (low permeability, pressure)
- Liquid CO_2 treatments may be very favorable:
  - non-damaging
  - solvent properties of CO_2
  - proppantless fracturing (or non-fracturing) approaches can reduce costs

POTENTIAL APPLICATION TO MARGINAL OIL/GAS WELLS (cont'd)

- **EOB treatments may not be applicable at the current state of technology:**
  - **uncertain reliability, results**
  - **operational complexity and cost**
- **Proppant methods, while results from this project are not yet available, may be favorable:**
  - **same principle, superior dynamics as EOB**
  - **operationally simple and low in cost**

ALTERNATIVE "NEW & NOVEL" LOW-COST STIMULATION METHODS FOR MARGINAL OIL & GAS WELLS

- Jetting
- Extended perforating
- Short-radius laterals
- Propellants
- Chemical methods
- etc.